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GB A 2144537
US 4585349
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G1A
Selected US specifications from IPC sub-classes G01B G01D G01J G06F G06K H03M

# (54) Optical transducers

(57) An optical transducer has an optical head 3 mounted above an optically encoded reflective member such as a disc 4. Broad band radiation is supplied via a fibre 2 to the head which may be a solid glass block with a curved reflecting surface (32) that collimates and reflects radiation onto a diffraction grating (44). Radiation is dispersed by the grating (44) and reflected back onto the curved reflecting surface (32). This causes the radiation to be focussed onto the member 4 as a spectrum (60). The head 3 combines radiation reflected from the member 4 and focusses it onto the end of a return fibre 7. A wavelength decoder 8 at the other end of the return fibre 7 disperses the received radiation onto an array 9 of photodiodes which provides an output representing the location of the reflective parts of the member 4 from which the position of the disc is determined. By measuring the separation between two reflective tracks (41), (42) on the member concentricity errors can be removed. If the member 4 is an encoder plate (70) rather than a disc, displacement in two co-ordinate directions can be measured by measuring the separation and absolute positions of reflected wavelengths. The position of the member 4, which may be encoded in analogue or digital form, may be a measure of temperature or pressure.

Fig. 1.

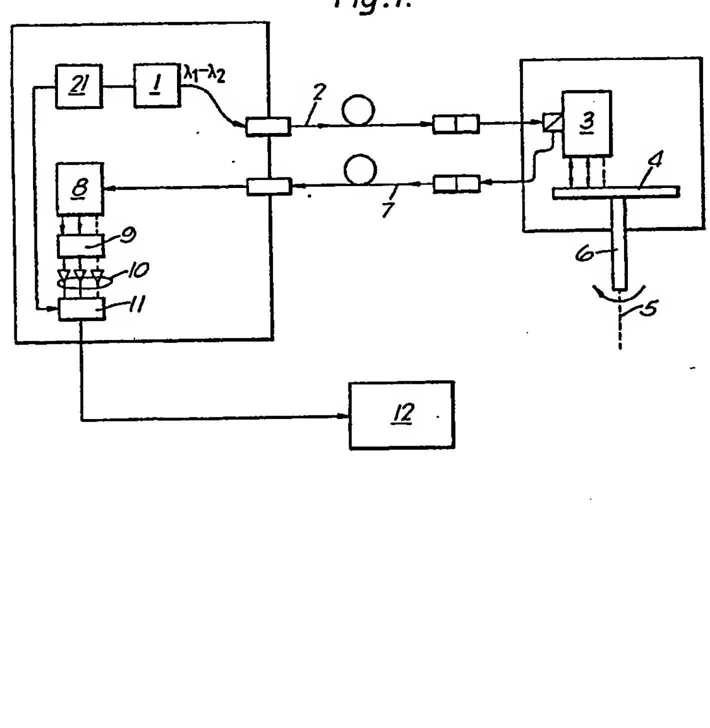


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Fig.1.

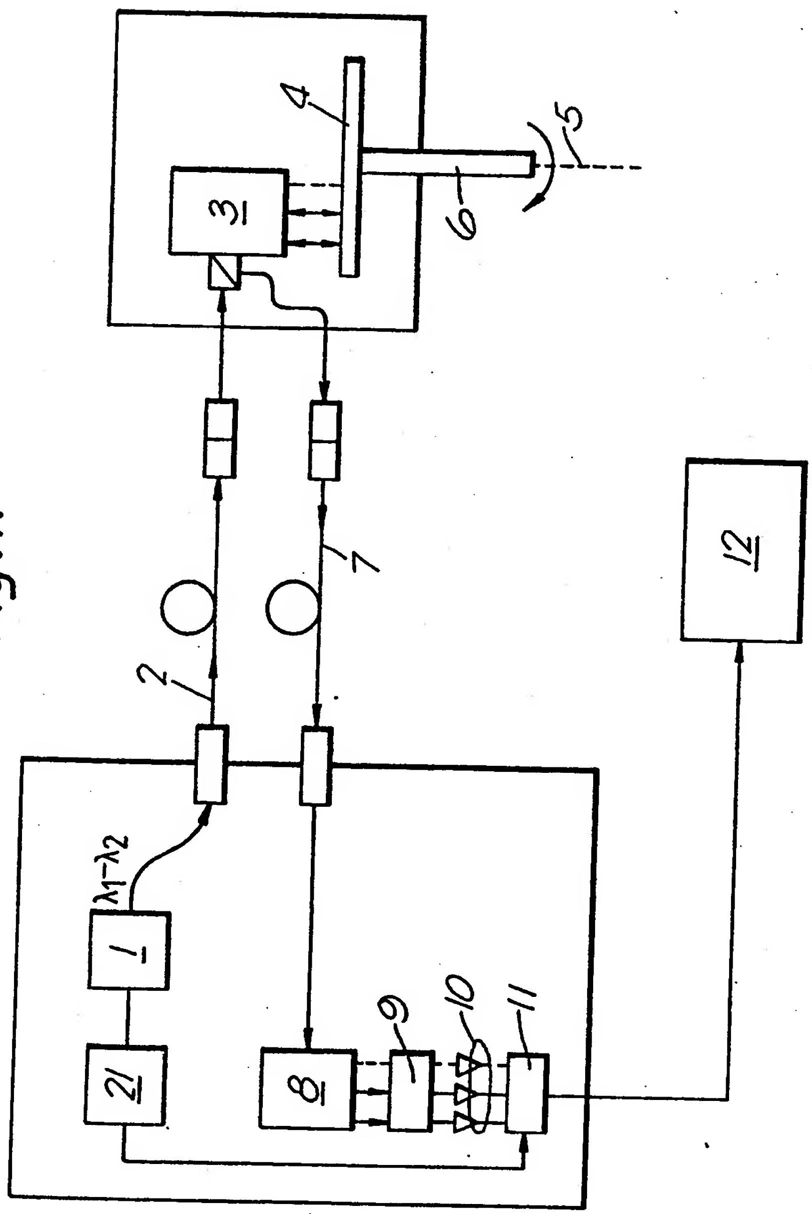


Fig. 2.

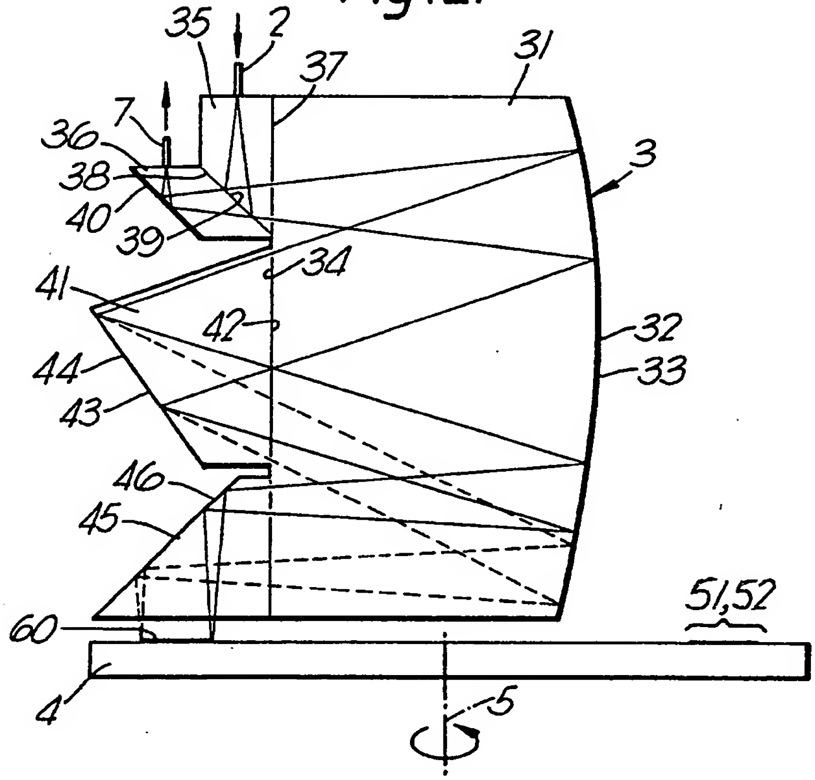

35
2
37
31
7
36
38
40
39
3
34
41
42
32
44
33
43
46
45
51,52
60
4
5

Fig. 3.

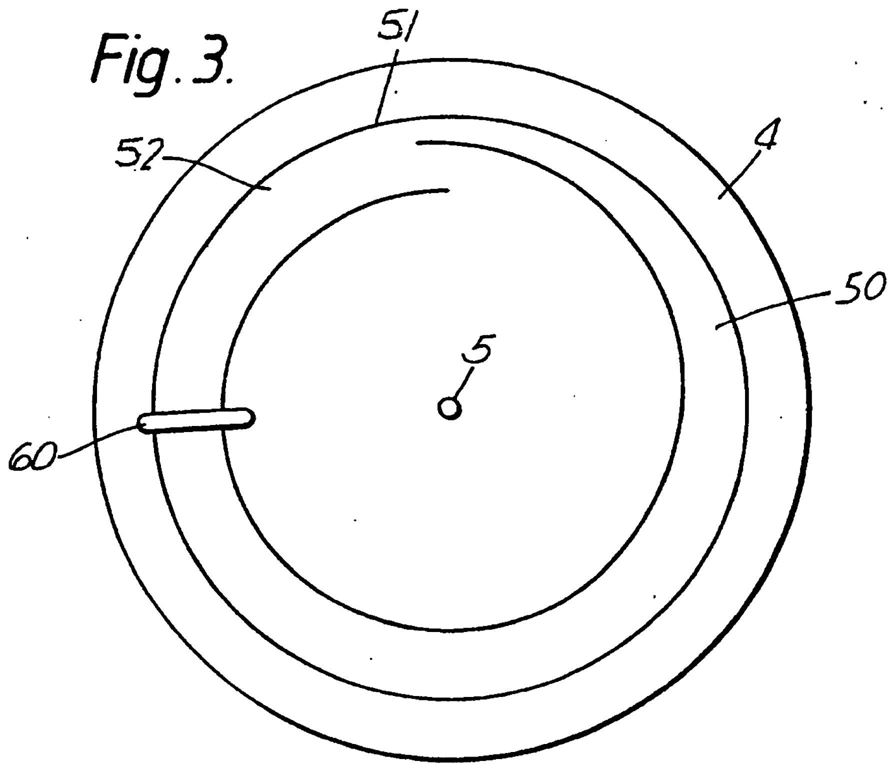
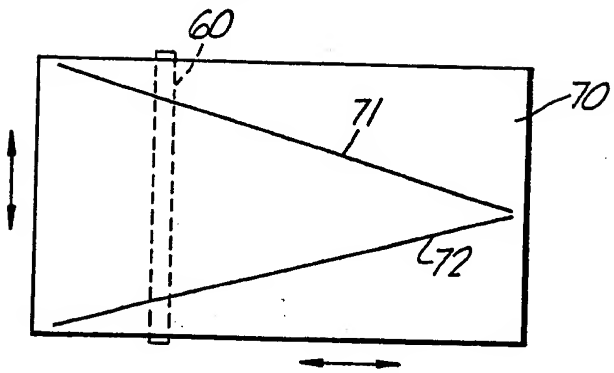

51
52
4
50
5
60

Fig. 4.



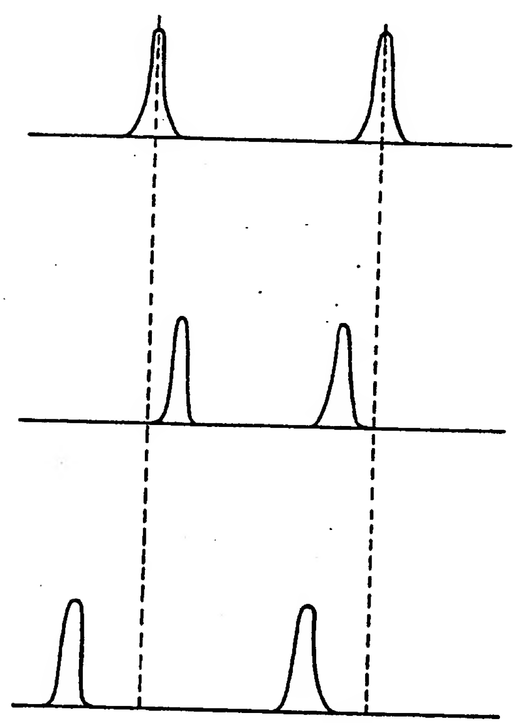



Fig. 4A.

Fig. 4B

Fig. 4C.

SPECIFICATION

## Optical transducers

This invention relates to optical transducers.

Optical displacement transducers are well known and generally employ a light source and receiver (such as provided by the ends of fibre-optic cables), and means to vary the amount of radiation falling on the receiver in accordance with displacement. The means by which the radiation is varied may employ a moveable mask with an aperture of variable size, or a neutral density filter the density of which varies along its direction of displacement. These transducers can function satisfactorily providing that the intensity of radiation falling on the receiver is not varied for any other reason. However, any change in the radiation emitted by the light source, such as, for example, caused by variations in power supply to the light source will produce erroneous displacement readings.

The effect of these variations in light intensity can be reduced by instead modulating the spectral content of the radiation in accordance with displacement. However, a problem with previous tranducers of this kind is that it can be difficult to achieve a linear output since devices for producing spectral dispersion are not linear, and because wavelength decoders usually do not present a linear output response.

In another arrangement light is dispersed into its spectral components and a coded mask is moved within the spectrum to allow different parts of the spectrum to be transmitted according to the position of the mask. The radiation passed by the mask is focussed on one end of a fibre-optic cable and is dispersed again at the other end of the cable. By measuring the intensity of radiation at different parts of the spectra it is possible to determine the position of the mask. The problem, however, with such an arrangement is that it is difficult to ensure that all the radiation transmitted through the mask is focussed on the end of the receiving fibre, because the image formed will be spread over the image plane by virtue of the dispersed nature of the spectrum imaged on the mask. There is also a problem in that, in some circumstances it may not be possible to use a transparent mask where access is required to both sides of the mask.

It is an object of the present invention to provide an optical transducer that can be used to alleviate the above-mentioned problems.

According to one aspect of the present invention there is provided an optical transducer including a source of optical radiation over a range of wavelengths, an optical head that is arranged to disperse the radiation into its component wavelengths along a region so that the wavelength of the radiation emitted by the optical head at any location along the region is dependent on the location along the region, and a displaceable member that is movable relative to the region in the path of the radiation, the displaceable member being optically encoded such that different wavelength radiation is reflected back to the optical head according to the position of the displaceable member, the optical head being arranged to deflect the reflected radiation according to its wavelength such that it is imaged on the end of a radiation guide, and the radiation guide extending to detector means that is arranged to respond to radiation at different wavelengths and thereby provide an output in accordance with the position of the displaceable member.

The optical head preferably includes a diffraction element that is arranged to disperse the radiation into its component wavelengths and to deflect radiation reflected via the displaceable member onto the radiation guide. The diffraction element may be a diffraction grating. The optical head preferably includes a converging reflective surface arranged to collimate and reflect radiation towards the diffraction element, to focus radiation on the displaceable member and to focus radiation from the displaceable member on the end of the radiation guide. The transducer may include a first radiation guide arranged to supply radiation from the source to the optical head and a second separate radiation guide arranged to supply radiation from the optical head to the detector. The first radiation guide may be a single fibre, fibre-optic cable. The second radiation guide may be a single fibre, fibre-optic cable. The optical head may be provided by a solid block of an optically-transparent material. The displaceable member may have reflective markings on a non-reflective background.

The displaceable member may be an analogue encoder, having two reflective tracks the separation of which varies according to the position of the encoder, the detector being arranged to respond to to the separation between the wavelengths reflected by the two tracks and to provide an output in accordance therewith. The displaceable member may be a rotatable disc, one reflective track being circular and centred on the axis of rotation of the disc, and the other track being spiral. The displaceable member may be movable in two directions at an angle to each other, the detector being arranged to respond to both the separation between the reflected wavelengths and the absolute value of the wavelengths and to provide an output in accordance with the position of the displaceable member along both directions. The displaceable member may be digitally encoded. The detector means, may include an array of photodetectors, each photodector being responsive to radiation reflected from a different part of the region.

An optical transducer in accordance with the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

*Figure 1* is a schematic diagram of the transducer;

*Figure 2* is a side elevation view of the optical head of the transducer;

*Figure 3* is a plan view of the displaceable encoder member used with the transducer;

*Figure 4* is a plan view of an alternative encoder member; and

*Figures 4A* to *4c* illustrate an output response for different positions of the alternative encoder

member.

With reference to Figure 1, the optical transducer includes a radiation source 1 of a range of wavelengths $\lambda_1$ and $\lambda_2$ provided by a light-emitting diode or other source, such as a tungsten lamp, and an electrical driver 21. Radiation from the source 1 is supplied via a single fibre, fibre-optic cable 2 to an optical head 3, which will be described in greater detail below. The optical head 3 disperses the radiation into its component spectrum and directs this onto an encoder disc 4 that is rotated about its axis 5 in accordance with changes in an input variable. In this respect, the input variable could, for example, be derived from a pressure or temperature sensor coupled to rotate an input shaft 6 of the encoder disc 4.

The encoder disc 4 reflects different parts of the spectrum back to the optical head 3 according to the position of the encoder disc. This reflected radiation is combined together in the optical head 3 and supplied to one end of a single fibre, fibre optic cable 7. The return cable 7 has its other end connected with a wavelength decoder 8 which disperses the radiation returned by the cable into its component wavelengths. The decoder 8 may include any conventional form of dispersion device such as a grating or prism. The spectrum formed by the decoder 8 is focussed on a linear array 9 of photodiodes or similar devices which provide output signals on lines 10 representative of the intensity of radiation at different parts of the spectrum. Because there will not usually be only one photodiode that is illuminated, but a spread over several photodiodes, a signal processor 11 is used to identify the peak illumination. The output from the signal processor 11 is supplied to a display device 12 on which is provided a display representation of the position of the encoder disc 4 which may be scaled to indicate directly the variable being monitored e.g. pressure or temperature. Alternatively, the output may be supplied to other utilisation means such as, for example, effects control in accordance with the measured variable.

If white light of sufficient intensity is used, some of the modified light may be split off and used to illuminate a point on a control panel. Such means would give a simple, direct indication of the state of a variable. For example, since red is at one end of the visible spectrum, this colour could indicate a dangerously high pressure, whilst green could indicate a safe pressure.

The optical head 3 will now be described in greater detail with reference to Figure 2. The optical head 3 is a solid glass block formed from several different glass elements joined to one another, although other optically transparent material could be used. The major part of the head 3 is provided by a generally rectangular collimating block 31 which has a spherical converging surface 32 on which is deposited a reflective coating 33. The opposite surface 34 of the collimating block 31 is plane and supports the other components of the optical head. These include two prismatic elements 35 and 36, joined to the upper end of the plane surface 34, by which radiation enters and leaves the head. The input element 35 has a plane surface 37, which abuts the plane surface 34 of the collimating block, and an inclined lower surface 38 which reflects input radiation into the collimating block 31 and which allows radiation emerging from the collimating block to pass into the output element 36. The output element 36 is of parallelepiped shaped, one face 39 of which abuts the inclined face 38 of the input element 35. The opposite face 40 is coated with a reflective material and reflects radiation to the return fibre 7.

Mounted on the plane surface 34, below the input and output elements 35 and 36, is a diffraction element 41. The diffraction element 41 is a glass block with a plane forward face 42, that abuts the collimating block 31, and an inclined rear face 43 on which is coated a reflective diffraction grating 44.

At the lower end of the plane surface 34 of the collimating block 31, there is mounted a prism element 45 with an inclined rear face 46 which is reflectively coated and which reflects radiation emerging from the collimating block 31 downwardly onto the encoder disc 4. Similarly, radiation reflected by the encoder disc 4 is reflected by the rear face 46 into the collimating block 31.

Following the radiation path through the optical head 3, it can be seen that radiation from the input fibre 2 enters the head in a vertical, downwards direction and that this radiation will be divergent. The surface 38 reflects the radiation, to the right, in the drawing, generally horizontally towards the reflective collimating surface 32. The curvature of the collimating surface 32 is such that it produces a parallel reflected beam of radiation that is directed to the left through the block 31 and onto the diffraction grating 44. The grating 44 produces dispersion of the incident radiation into its component spectrum to produce a reflected beam that is spread between the solid and broken lines in the drawing. The dispersed radiation is directed back onto the collimating surface 32 which converges the incident radiation and directs it back, to the left, to the prism element 45. The radiation is reflected downwardly by the rear face 46 of the prism 45 and is focussed onto the surface of the encoder disc 4. The radiation is therefore dispersed into its component wavelengths in a spectrum 60 that extends along a region arranged radially of the disc 4.

Radiation reflected from the encoder disc 4 follows the same path back through the optical head 3 to the diffraction grating 44. The radiation reflected from the encoder disc 4 onto the diffraction grating 44 will be deflected at an angle dependent on the wavelength of the radiation. After reflection by the converging surface 32, the radiation reaches the inclined surface 38 of the input block 35. The rear surface 38 of the input block 35 and the forward surface 39 of the output block 36 function together as a beam splitting surface so that a proportion of the radiation reflected from the encoder disc 4 is transmitted by the surfaces 38 and 39 to the reflecting face 40 where the radiation is reflected to the return fibre 7. The grating 44 ensures that all radiation reflected by the encoder disc is imaged at the same point on the end of the return fibre 7.

It can be seen that, by using the optical head 3, radiation is dispersed prior to being imaged on the encoder disc 4 and that those wavelengths reflected by the reflected tracks on the encoder disc are recombined by the grating 44. In this way, the small diameter object formed by the end of the input fibre 2 is spread out along the spectrum 60 on the encoder disc 4 and the reflected radiation is combined and focussed back to a small diameter image on the end of the return fibre 7. The image focussed on the end of the return fibre 7 is therefore the same size as the end of the input fibre 2, thereby ensuring a maximum efficiency when the return fibre is of the same diameter as that of the input fibre.

By using a reflective encoder, the same optical head is used to disperse and combine, thereby avoiding the need to provide a separate combiner with the additional expense and size that this would involve. Also, by using a reflective encoder, there is no need to have access behind the encoder. This enables encoding markings to be provided on an opaque member such as a flywheel.

Because the collimating surface 32, the grating 44 and the reflecting surfaces 38, 45 and 40 are all provided on a solid block, the risk of relative movement between the surfaces on vibration is reduced.

It would be possible to use the same fibre cable to supply and receive radiation. However, if connectors are included in the cable, there is the risk that reflection will occur at the connectors and that some input radiation will be supplied to the decoder making it difficult to distinguish from reflected radiation.

One form of encoder disc 4 is shown in Figure 3. This has a non-reflective background 50 and reflective markings in the form of tracks 51 and 52. The outer track 51 is circular with its centre on the axis 5 of the disc. The inner track 52 has a spiral shape so that the distance between the two tracks 51 and 52 varies around the disc 4. The spectrum formed on the disc 4 is indicated by the region 60 which extends radially across both tracks. As the disc is rotated, different parts of the spectrum will be reflected back to the optical head 3 from the spiral track 52. The circular track 51, will reflect back radiation from the same part of the spectrum, assuming that the track is formed concentrically. However, by measuring the distance between the two tracks, as in the present arrangement, the transducer is insensitive to concentricity errors in the encoder disc.

Alternatively, the encoder disc could be digitally encoded such as using the Gray coded system.

The encoder need not be in the form of a rotatable disc, as described above, but could be a plate that is movable along its length. One form of such a plate 70 is shown in Figure 4 which has two reflective tracks 71 and 72 that extend along its length. The tracks 71 and 72 are inclined towards one another across the width of the plate 70 so that their separation varies along its length.

With this form of plate it is possible to measure both movement of the plate along its length and at right angles across its width. Figure 4A shows the output response of the photodiode array 9 for the plate 70 in the position, with respect to the imaged spectrum 60, shown in Figure 4. If the plate 70 is moved to the left, the separation between those parts of the tracks 71 and 72 on which the spectrum 60 is imaged becomes less, and the output peaks of the response therefore come closer together, as shown in Figure 4B. If, however, the plate 70 is moved across its width, without displacement along its length, the separation between the peaks in the response will remain unchanged, but their absolute position will change, as shown in Figure 4C. By monitoring the absolute position of these peaks it is therefore possible to monitor displacement of the plate in two co-ordinate directions.

CLAIMS

1. An optical transducer including a source of optical radiation over a range of wavelengths, an optical head that is arranged to disperse the radiation into its component wavelengths along a region so that the wavelength of the radiation emitted by the optical head at any location along the region is dependent on the location along the region, and a displaceable member that is movable relative to the region in the path of the radiation, wherein the displaceable member is optically encoded such that different wavelength radiation is reflected back to the optical head according to the position of the displaceable member, wherein the optical head is arranged to deflect the reflected radiation according to its wavelength such that it is imaged on the end of a radiation guide, and wherein the radiation guide extends to detector means that is arranged to respond to radiation at different wavelengths and thereby provide an output in accordance with the position of the displaceable member.

2. An optical transducer according to Claim 1, wherein the optical head includes a diffraction element that is arranged to disperse the radiation into its component wavelengths and to deflect radiation reflected via the displaceable member onto the radiation guide.

3. An optical transducer according to Claim 2, wherein the diffraction element is a diffraction grating.

4. An optical transducer according to Claim 2 or 3, wherein the optical head includes a converging reflective surface arranged to collimate and reflect radiation towards the diffraction element, to focus radiation on the displaceable member and to focus radiation from the displaceable member on the end of the radiation guide.

5. An optical transducer according to any one of the preceding claims, wherein the transducer includes a first radiation guide arranged to supply radiation from the source to the optical head and a second separate radiation guide arranged to supply radiation from the optical head to the detector.

6. An optical transducer according to Claim 5, wherein the first radiation guide is a single fibre, fibre-optic cable.

7. An optical transducer according to Claim 5 or 6, wherein the second radiation guide is a single

fibre, fibre-optic cable.

8. An optical transducer according to any one of the preceding claims, wherein the optical head is provided by a solid block of an optically-transparent material.

9. An optical transducer according to any one of the preceding claims, wherein the said displaceable member has reflective markings on a non-reflective background.

10. An optical transducer according to any one of the preceding claims, wherein the displaceable member is an analogue encoder having two reflective tracks the separation of which varies according to the position of the encoder, and wherein the detector is arranged to respond to the separation between the wavelengths reflected by the two tracks and to provide an output in accordance therewith.

11. An optical transducer according to Claim 10, wherein the displaceable member is a rotatable disc, wherein one reflective track is circular and centred on the axis of rotation of the disc, and wherein the other track is spiral.

12. An optical transducer according to Claim 10, wherein the displaceable member is movable in two directions at an angle to each other, and wherein the detector is arranged to respond to both the separation between the reflected wavelengths and the absolute value of the wavelengths and to provide an output in accordance with the position of the displaceable member along both directions.

13. An optical transducer according to any one of Claims 1 to 9, wherein the displaceable member is digitally encoded.

14. An optical transducer according to any one of the preceding claims, wherein the detector means includes an array of photodetectors, and wherein each photodetector is responsive to radiation reflected from a different part of the region.

15. An optical transducer substantially as hereinbefore described with reference to Figures 1 to 3 of the accompanying drawings.

16. An optical transducer substantially as hereinbefore described with reference to Figures 1 to 3 as modified by Figures 4 and 4A to 4C of the accompanying drawings.

17. Any novel feature or combination of features as hereinbefore described.

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